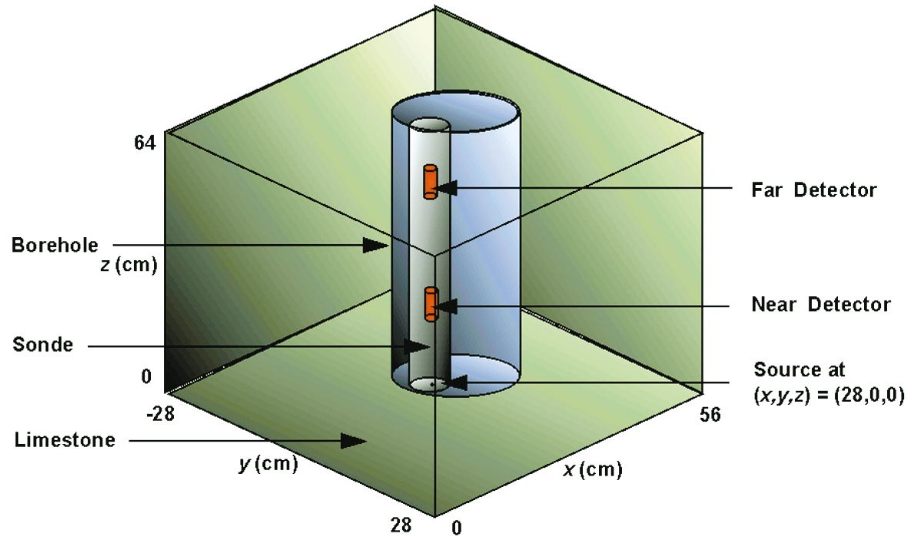
University of California
Lawrence Livermore National Laboratory

In collaboration with
Halliburton Corporation

Nuclear Well Logging

Computer Simulation of Nuclear Well-Logging Devices



A typical well logging configuration.

Technology

We use parallel deterministic numerical methods to solve the three-dimensional multigroup, neutron/radiation tranpsort equation on massively parallel architectures, enabling high resolution simulations of nuclear well logging tools.

Application

We are performing high resolution computer simulations of nuclear well logging tools to aid in determining the lithology, porosity, and fluid characteristics of the surrounding materials near a borehole.

Problem Description

Nuclear well logging is a method of studying the materials surrounding exploratory boreholes. A tool consisting of a neutron or gamma-ray source and one or more detectors is lowered into the borehole. The response of the detectors to radiation returning from outside the borehole depends in part on the lithology, porosity, and fluid characteristics of the material. In principle, the characteristics of the materials outside the borehole can be inferred from the response of the detectors.

Well logging is widely used in the oil industry. The interpretation of the data is based on benchmark measurements in a known environment, comparison with data from other types of measurements, and computer simulation of the measurements with neutron and gamma-ray transport codes.

The computer simulation is done by calculating the response of a tool to a given material using the linear Boltzmann equation and libraries of neutron and photon cross-section data widely available. The ability to calculate responses greatly enhances the ability to design optimum tools and to interpret their response, because different tool designs or material combinations can be investigated with calculations rather than with expensive experiments.

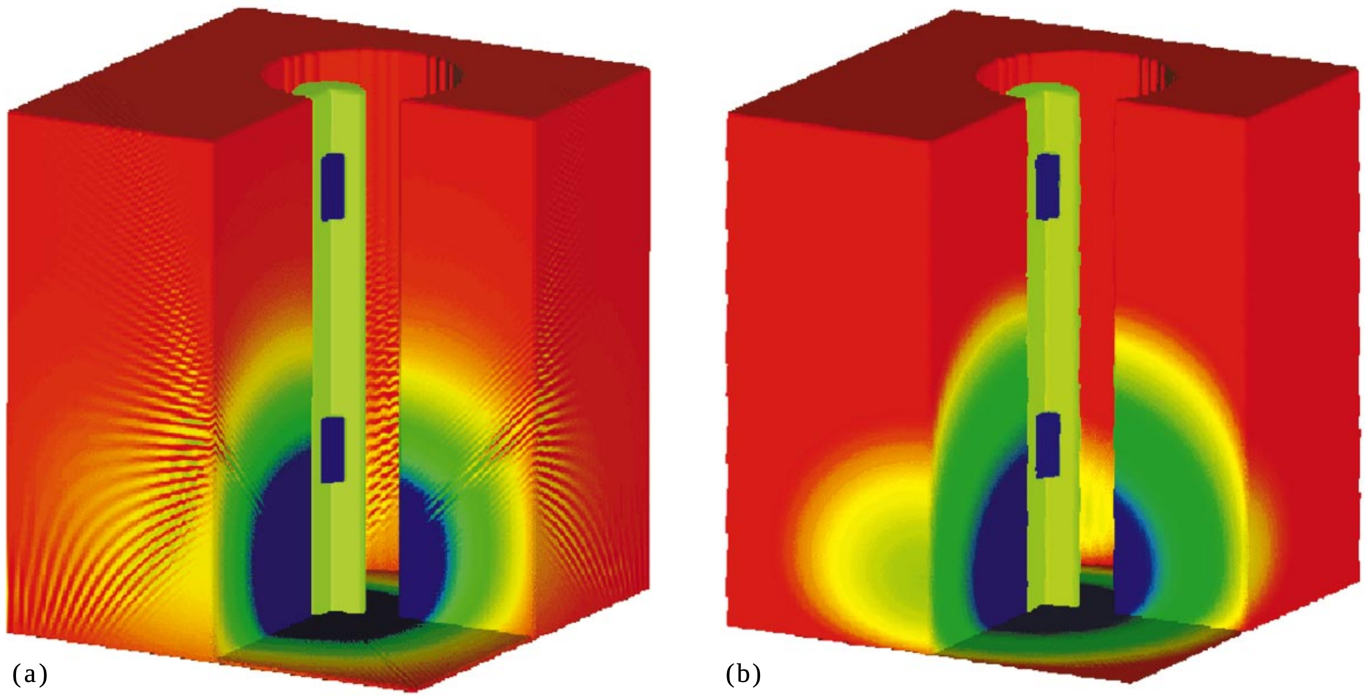
In practice the computational approach has proven difficult for the following reasons:

- The problem is intrinsically three dimensional, which means that all six dimensions of phase space appear as independent variables.
- Some tools depend on a time-dependent response, which adds another variable.
- The problem is inherently “thick,“ because the particles (neutrons or gamma rays) must travel into the material, interact, and travel back to one of the detectors.
- The geometry is awkward, because the critical dimensions of the tool are small, but the interaction with the material takes place over quite a large volume.

The current practice is to use the Monte Carlo method for these calculations. In Monte Carlo, one takes a random sample of the phase space. This method often makes it possible to get answers to problems that are too complex to solve by more conventional methods. Because a random process is used, all results come with some statistical uncertainty. Different answers are obtained for the same problem simply by changing the sequence of random numbers. This may be particularly troublesome in problems where the desired answer is the ratio of responses of two detectors, each with its own statistical error. The additional statistical error makes it difficult to compare responses from two similar materials, because the statistical error may be comparable in magnitude to the material effects. This type of error decreases only as one divided by the square root of H, where H is the number of histories. Thus, the answer converges slowly as more computer power is applied.

Problem Solution

We use a finite element solution of the transport equation. The method developed at LLNL allows us to represent complicated geometry with a grid optimized for transport purposes. The density profiles of the different materials in the problem can be integrated directly with the functions used to represent the neutron or



These images show the solution to the nuclear well logging problem stated in the text for (a) water-filled borehole using a conventional discrete ordinates (i.e., with ray effects) and (b) with our new solution method eliminating the ray effects.

gamma fluxes. Our experience indicates that accurate solutions for complex geometry are obtained in this manner, even in three dimensions, using a reasonable number of zones. We have developed methods for solving this class of equations efficiently on modern computers. We also use special methods for treating the relatively small sources and detectors in these problems. These methods include a special calculation of first flights of the particles, as well as techniques for mitigating the persistent "ray" effects typically present in deterministic solutions of the Boltzmann equation due to finite spatial and angular zoning.

At LLNL, we have used deterministic methods for solving complex transport problems for a number of years. Some of the codes used in our applied physics studies are among the fastest and most efficient in the world. In particular, we have used deterministic codes with great success in solving three-dimensional physics problems previously considered tractable only by Monte Carlo methods. Also, we have developed methods for using massively parallel computers to solve our transport algorithms quickly and efficiently.

In the future, we will extend our solution method to time-dependent problems. We have had extensive experience with time-dependent deterministic methods, both explicit and implicit.

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